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Construction of a Double Beam VUV Spectrometer

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A double beam detection system for the vacuum ultraviolet has been developed which when utilized with a hydrogen light source, effectively eliminates the shortcomings of a conventional single beam system. An alternating light from a monochromator has been divided into two beams by using a LiF plate. The servo system composed of one lock-in amplifier and associated electronic circuits allows one to plot continuously optical spectra of materials by scanning the photon energy. This enhances the structures of the spectra as compared to the conventional system.

1. Introduction

In the vacuum ultraviolet spectroscopy, a hydrogen arc is commonly used as a conventional light source. It gives a continuous spectrum with relatively low intensity up to 7.5 eV of the photon energy and is very rich in lines in the region 7.5 - 12 eV. The spectral distribution of the source, however, is very sensitive to the gas pressure. Measurements must be repeated several times until a reproducible result is obtained, as far as the measurements are carried out after a conventional single beam detection method. The method needs, furthermore, a tedious labor for dealing with a number of numerical data associated with the individual lines of the source spectrum.

We peport the construction of a double beam spectrometer, which when utilized with its associated electronic servo system, effectively eliminates the shortcomings mentioned above. The spectrometer allows one to plot continuously absorption or reflection spectra of materials by scanning the photon energy. This enhances the structures of the spectra as compared to the conventional single beam spectrometer. Parts of the optical studies made by using the present spectrometer have previously

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been reported.[1),2)]

2. Double Beam Detection System

In Fig.1 is shown a schematic view of the double beam detection system for measuring the reflection spectra. The light from a hydrogen discharge tube is chopped at a frequency of about 86 Hz by a cylindrical beam chopper inside the vacuum ultraviolet monochromator of a 40 cm Seya-Namioka type equipped with an MgF_2 coated grating (1200 groved per mm, blazed at 2064 A). The monochromatic light emerging from the monochromator is incident at 45° on a platelet of LiF (from Harshow Chemical Co.) to split the light into transmitted and reflected beams, with the plane of incidence rotated 45° with respect to the plane defined by the exit slit and the light path. An another LiF platelet was placed in position across the reflected light path in order to work with compensated beams. The intensity of the reflected light is measured with a HTV 1P21 photomultiplier(PM1) by using a sodium salicylate phosphor. The transmitted light is let into a reflectometer through a LiF window and is reflected by a sample to the glass window of the second photomultiplier(PM2) on which the sodium salicylate is directly coated.

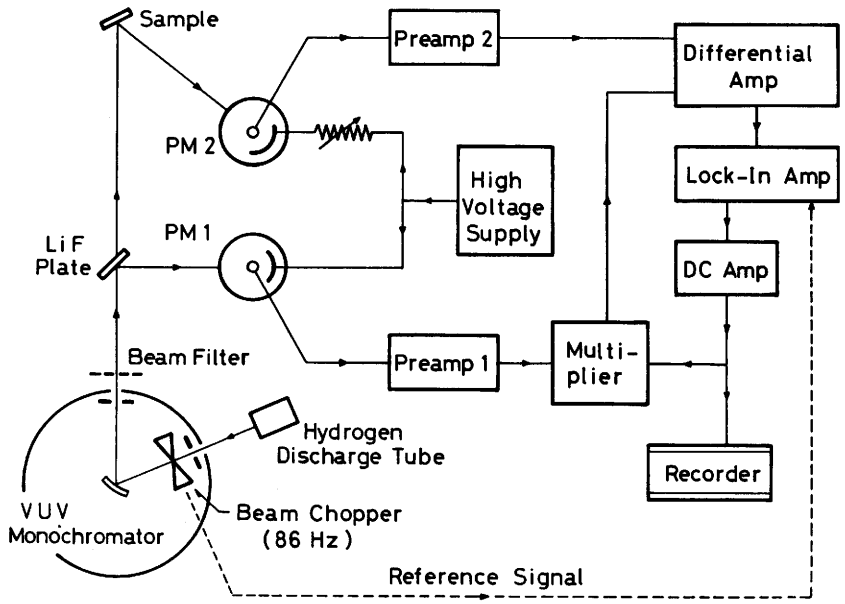


Fig. 1 A schematic view of a double beam spectrometer for studying the optical properties of materials in the vacuum ultraviolet.

The output currents from PM1 and PM2 are proportional to $R_0(\lambda)I(\lambda)$ and $[1 - R_0(\lambda)]R(\lambda)I(\lambda)$ respectively, where R_0, R and I are the beam splitter reflectivity, sample reflectivity, and light intensity. The sample reflectivity R can be obtained from the ratio between the two currents. Rather than trying to obtain the ratio directly from the two currents by using a simple divide mode of electronics, we utilize the servo system for minimizing the noise levels due to instantaneous fluctuations of the ligh source. The system is composed of a multiplier, a differential amplifier, a lock-in amplifier and a dc amplifier as shown in Fig.1. The output of the multiplier, which is proportional to $S(\lambda)R_0(\lambda)I(\lambda)$ where S is the feedback voltage of the system, is compared with the signal from PM2 by the differential amplifier whose output is measured with the lock-in amplifier.

Equilibrium of the servo system is reached when the feedback voltage S is equal to

$$A[(1 - R_0(\lambda))R(\lambda)I(\lambda) - \alpha R_0(\lambda)S(\lambda)I(\lambda)], \quad \cdots\cdots\cdots (1)$$

where α is a constant factor associated with the multiplier and A the total gain of the dc- and the lock-in amplifiers. Thus the servo system is at equilibrium under the condition of

$$S(\lambda) = \frac{A[1 - R(\lambda)]R(\lambda)I(\lambda)}{\alpha A R_0(\lambda)I(\lambda) + 1} \quad \cdots\cdots\cdots (2)$$

When the total gain A is high enough that the first term in the denominator of eq.(2) is very large compared to the 1, the feedback voltage $S(\lambda)$ which is plotted with a chart recorder is proportional to the sample reflectivity $R(\lambda)$ independently of the light intensity $I(\lambda)$:

$$S(\lambda) = S_0(\lambda)R(\lambda), \quad S_0(\lambda) = \frac{1 - R_0(\lambda)}{\alpha R_0(\lambda)} \quad \cdots\cdots\cdots (3)$$

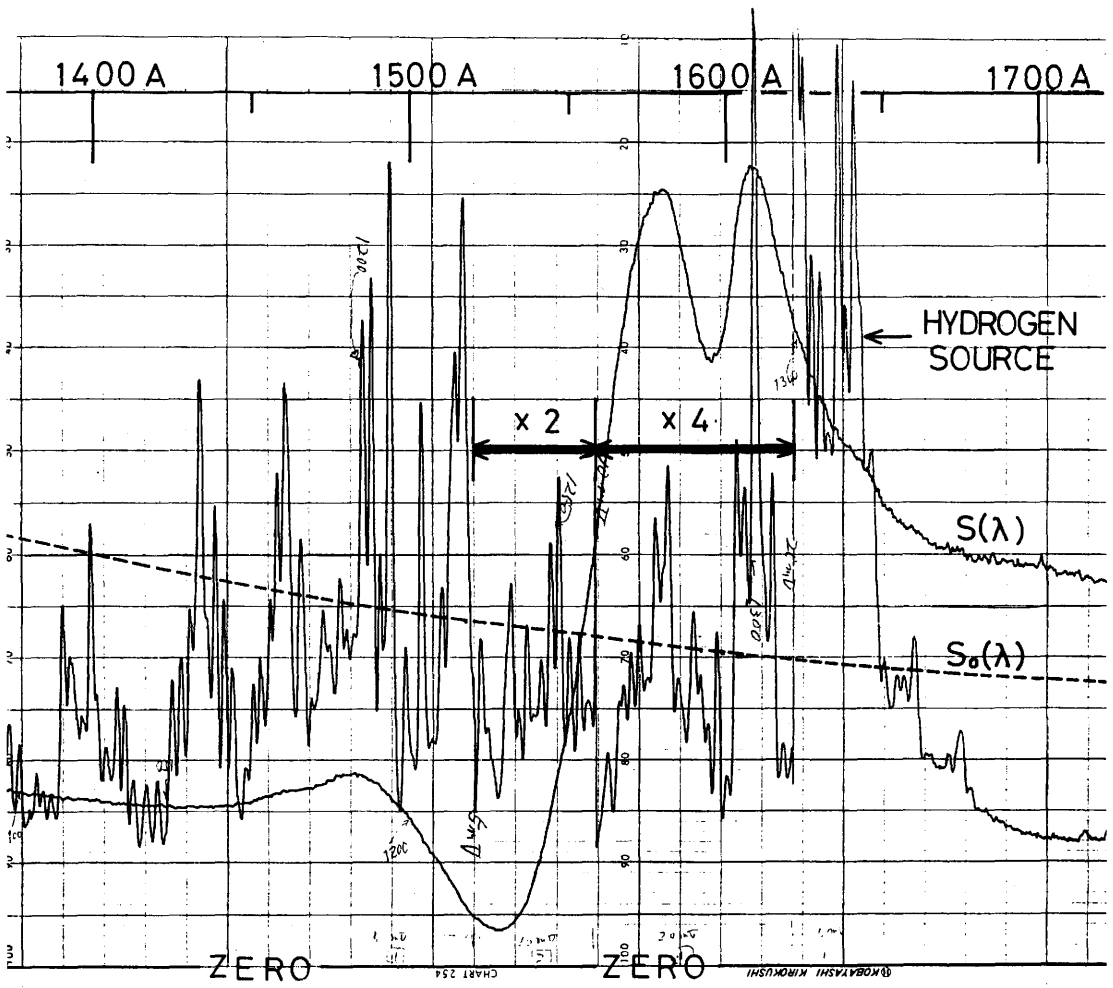
The value of $S_0(\lambda)$, which varies slowly with the photon energy on account of the wavelength dependence of the reflectivity of the LiF beam splitter, can be directly determined by measuring the feedback voltage for the case where the transmitted light from the beam splitter is directly let to PM2. Once the *'correction'* curve $S_0(\lambda)$ is obtained, the sample reflectivity $R(\lambda)$ can be determined from the *'apparent'* reflectivity spectrum $S(\lambda)$.

3. Performance

The double beam spectrometer is now used for the reflection measurements of materials in the hydrogen light source region. The spectrometer allows one to plot continuously the reflection spectra even at the valleys between the line spectral maxima of the hydrogen arc by keeping

the resolution of the monochromator better than 1.5 A in the whole energy region of the hydrogen line spectrum. It is at this point that the present development of the double beam spectrometer does ensure the advantage over the conventional style of point-by-point measurements.

In Fig.2 is shown an example of the *'apparent'* reflection spectrum ($S(\lambda)$) of KCl plotted on a pen recorder, together with the line spectrum



Fif. 2 An example of an *'apparent'* reflection spectrum ($S(\lambda)$) of KCl plotted on a pen recorder and a line spectrum of the hydrogen light source. The true reflectivity of KCl is given by the product of $S(\lambda)$ and $S_0(\lambda)$.

of the hydrogen light source. Each of these spectra was measured individually by keeping the resolution of the monochromator at the value of about 1.5 A. The dotted curve of the figure is the *'correction'* curve

($S_0(\lambda)$) which was also measured at the same resolution. This curve coincides well with the reflectivity of 45° incidence of the LiF plate computed from refractive indices by taking into account the back surface reflection of the plate. The spectrum $S(\lambda)$ is well stabilized even at the valleys bwtween the line spectral maxima of the light source, and has a smooth curve in the whole energy region in spite of considerable variations in the spectral intensities of the individual lines. (It is noted that the intensity ratio of the line spectral maximum at 1608 A to that at about 1315 A is more than 70.) The true reflectivity of the sample is given by the product of $S(\lambda)$ and $S_0(\lambda)$ (see eqs. (3)).

Experience has shown some undesirable dependence of the curve $S(\lambda)$ on the individual lines of the hydrogen arc in the case where the input signal of the multiplier from the preamplifier 1 (see Fig.1) is very weak. According to eq. (2), the dependence of the feedback voltage $S(\lambda)$ on the light intensity $I(\lambda)$ has the approximate form:

$$S(\lambda) = S_0(\lambda)R(\lambda)\left[1 - \frac{1}{\alpha A R_0(\lambda) I(\lambda)}\right]. \qquad \cdots\cdots\cdots (4)$$

The second term in the bracket, which is responsible for the shortcoming mentioned above, is inversely proportional not only to the light intensity $I(\lambda)$ but also to the total gain A. In fact, the shortcoming was overcome by increasing the gain A, although the feedback voltage $S(\lambda)$ appeared to be very sensitive to the photon shot noise. It is noted, however, that the curve $S(\lambda)$ with a considerable signal-to-noise ratio was obtained by increasing, proportionally to the gain A, the time constant of the lock-in amplifier and by reducing the speed of the wavelength scan of the monochromator.

The measurement of the $S(\lambda)$ shown in Fig.2 was carried out at the scanning speed of 1.25 cm per minute for the case where the total gain A of the dc- and lock-in amplifiers and the constant factor α associated with the multiplier were 4×10^3 and $(10 \text{ volt})^{-1}$ respectively. The time constant of the lock-in amplifier was 10 second. The input signal of the multiplier from PM1 was so amplified by the preamplifier 1 as to be more than 0.1 volt, that is, 0.1 volt at 1315 A, while 7.6 volt at 1608 A. Thus the second term in the bracket in eq. (4) is less than 2.5×10^{-2} which is very small compared with the 1.

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